Flexible User Radio for Lunar Missions

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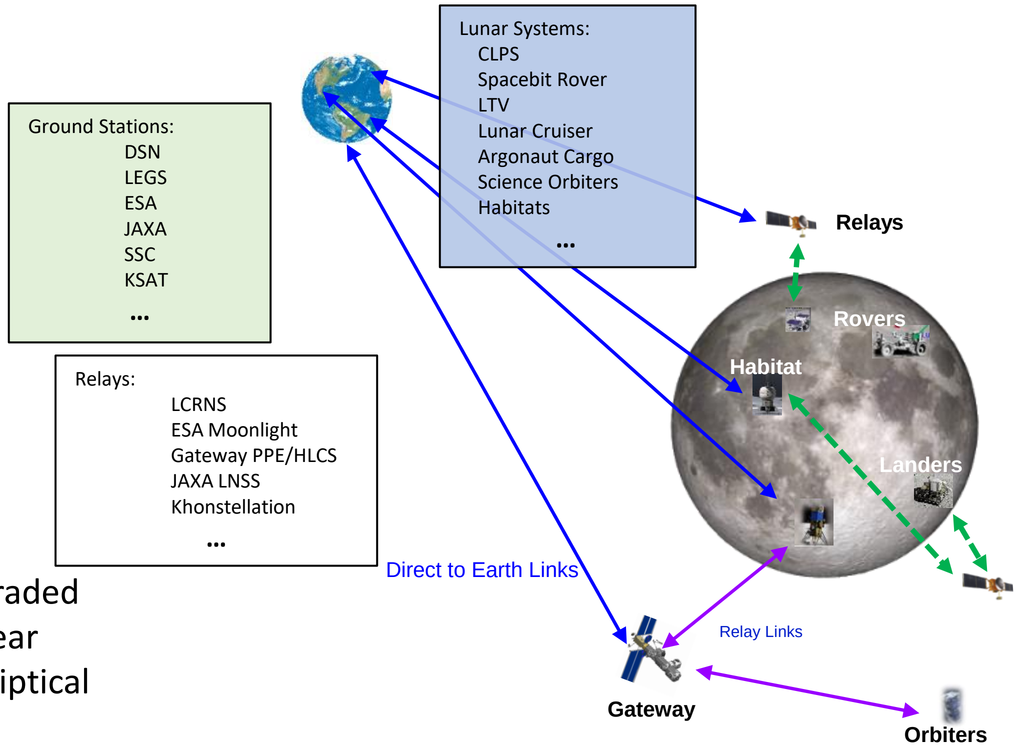
Introduction

- Unprecedented Lunar Activity
  - Landers
  - Orbiters
  - Rovers
  - Habitats
- All require Communications
  - Various Locations
    - Near Side
    - South Pole
    - Far Side
    - Low Lunar Orbit
  - Options
    - Direct to Earth
      - Ground stations being upgraded
    - Relays: Low Lunar Orbit (LLO), Near Rectilinear Halo Orbit (NRHO), Elliptical Frozen Orbit (ELFO)
      - Relays do not currently exist



Design Challenge

Flexible User Radio for Lunar Missions

- Communication Subsystem Design presents a Planning Challenge

  A) Choose a Communication partner with a system in development and design for compatibility
  - Dependency on partner development schedule
  - Capabilities
  - Availability

  B) Choose existing network
  - Accept existing capabilities
    - Or accept dependency on upgrade schedule
  - Availability

  C) Develop independent network
  - Cost
  - Dependency on Schedule
  - Capabilities

  D) Design to Standard then seek a partner
  - Dependency on partner development
  - Risk of compatibility

- Future Adaptability

  - Beyond initial operation, dependency on a single communication network creates issues of reliability and limited growth path

Proposal – Flexible Lunar Radio

- To support interoperability with a broad range of networks, the Flexible Lunar Radio must be adaptable/reconfigurable in the following parameters:

  - Power Levels
    - Maximum and Minimum
    - Transmit and Receive
  - Frequencies
    - Including Doppler
  - Antenna Polarization
  - Bandwidth
  - Modulation
  - Ranging
  - Error Correction
  - Data Rate
  - Framing format
  - Packetization
  - Network Protocols

Notional Design – Flexible Lunar Radio

Flexible User Radio for Lunar Missions

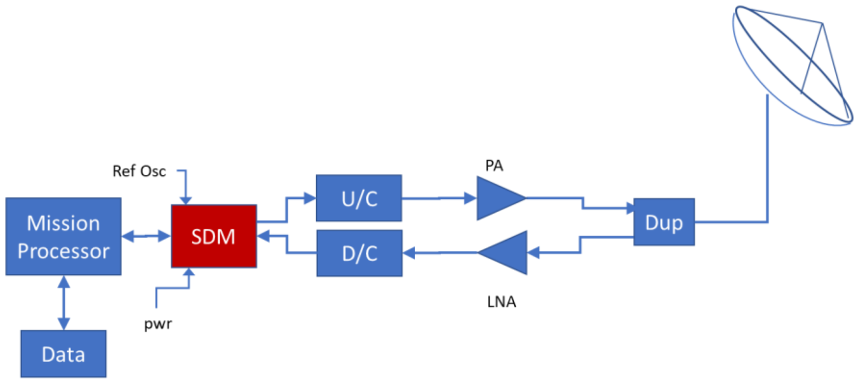
- Communication Scenarios
  - Direct to Earth using Lunar Exploration Ground System (LEGS) 18 m ground station
  - NRHO relay using Gateway 1.5 m antenna
  - ESA Elliptical Frozen Orbit using 0.5 m antenna

- Lunar System Reference Spacecraft
  - Large Lunar Lander with steerable antenna
  - Small Lunar Lander with phased array
  - Orbiter with phased array

- Given those scenarios, the EIRP and G/T values are calculated
  - Values found to be realistic and achievable

- Required Modulation and Coding schemes can be implemented in Software Defined Modem

- A Flexible Lunar Radio as shown can be designed into a small, light-weight, low power package



Ref Mission	Transmit EIRP (dBW)	Receive G/T (dB/K)
Large Lander	58.1	19.6
Small Lander/Orbiter	28.1	-10.4

Notional Requirements

Frequencies:

Ka-band allocations in the ICSIS*:

Earth to Orbit FL:	22.55 – 23.15 GHz
Orbit to Lunar Surface FL:	23.15 – 23.55 GHz
Orbit to Earth RL:	25.5 – 27.0 GHz
Lunar Surface to Orbit RL:	27.0 – 27.5 GHz

Total bandwidth: 1 GHz Receive, 2 GHz Transmit

Coding:

LDPC 1/2, 2/3, 4/5, 7/8
Turbo codes
Concat. Viterbi/Reed-Solomon

Modulation:

OQPSK, BPSK, GMSK
PCM/PM/Bi-phase-L
PCM/PSK/PM+NRZ-L
DVB-S2

Ranging:

PN turnaround

*International Communication System Interoperability Standards (ICSIS), Rev. A, September 2020.

Flexible Lunar Radio Implementation

- Many Key Technologies required for creating a Flexible User Radio are already being developed

  - Wideband Terminal (WBT)
  - Software Defined Radio (SDR)
  - Adaptive/Cognitive Communications
  - Delay Tolerant Networking (DTN)

Wideband Terminal

- The Wideband Terminal (WBT) is a demonstration project to enable spacecraft in near Earth orbit to communicate using commercial satellite relays in addition to TDRSS

  - Supports 17.7 – 23.55 GHz receive, 25.25 – 31 GHz transmit
  - Variable Coding and Modulation
    - Interoperability demonstrations performed in 2021

  - Additional modifications would be required to adapt to the Lunar environment
    - Power Levels
      - Power Amplifier backoff
    - Doppler Tolerance

Software Defined Radio

- Software-Defined Radios and Software-Defined Modems are now common in spacecraft
  - Flexible radio requires broad range of modulation, coding, and ranging support

- Full Flexibility requires the ability to re-program post-launch
  - Less frequently demonstrated

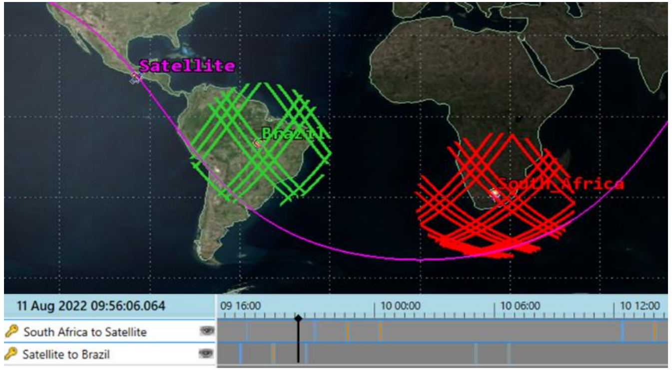
Adaptive/Cognitive Communications

- Adaptive/Cognitive Communications
  - NASA's Cognitive Communications project is pursuing development of decentralized space networks with artificial intelligence agents optimizing communication link throughput, data routing, and system-wide asset management.
  - The Flexible Lunar Radio will be able to select, reconfigure, and interoperate among available communication links options, in near-real time.
  - If Flexible Radios are widely deployed among many lunar users, the combined flexibility creates network-wide optimization opportunities

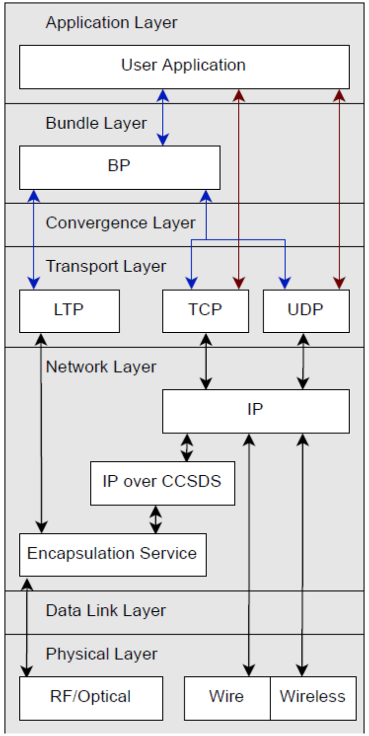
Delay Tolerant Networking

Flexible User Radio for Lunar Missions

- Delay Tolerant Networking
  - Developed to adapt to space environment
    - Long delays
    - Intermittent outages
    - Variable data rates
  - Introduces Bundle Protocol above convergence layer
    - Supports Store and Forward
- Implemented in Firmware
  - Software Defined Networking (SDN)



LEO Example: message from Brazil stored on-board LEO satellite until South Africa comes into view



Modified OSI model, including Bundle Layer

Conclusion

Flexible User Radio for Lunar Missions

- The diverse and dynamically changing environment of lunar systems and communications capabilities creates a complex set of dependencies and uncertainties.

- Flexible Lunar Radio frees system engineers from communications dependencies in the early stages of development
    - Provides upgrade path into the future

- Many of the technologies required exist or are in development
    - Wideband Terminal
    - Software Defined Radio
    - Cognitive Communications
    - Delay Tolerant Networking